

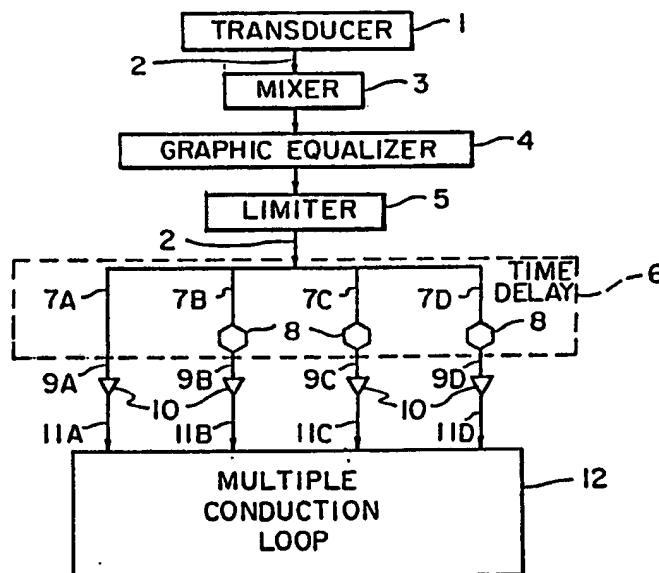


INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : H04B 5/00	A1	(11) International Publication Number: WO 90/13953 (43) International Publication Date: 15 November 1990 (15.11.90)
(21) International Application Number: PCT/US90/01281 (22) International Filing Date: 12 March 1990 (12.03.90) (30) Priority data: 349,515 9 May 1989 (09.05.89) US (71)(72) Applicant and Inventor: LEDERMAN, Norman [US/US]; 78 Main Street, Yarmouth, ME 04096 (US). (74) Agent: BOHAN, Thomas, L.; 371 Fore Street, P.O. Box 403, Portland, ME 04112 (US). (81) Designated States: AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CF (OAPI patent), CG (OAPI patent), CH, + CH (European patent), CM (OAPI patent), DE, DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NL (European patent), NO, RO, SD, SE, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent).		Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

(54) Title: INDUCTION-BASED ASSISTIVE LISTENING SYSTEM**(57) Abstract**

The object of the invention is to provide a multiple-loop magnetic induction system for improving communication with the hearing-impaired or to people in general who wish to listen privately to speech or music while being in the company of others or at a public location. The induction system has a series of conduction loops (13A-D) incorporated into a multiple conduction loop array (12). Each of said conduction loops (13A-D) receives substantially equivalent amplified voltage signals (11A-D), each of which has been delayed and each of which corresponds to a particular conduction loop (13A-D). Said voltage signals (11A-D), originate from an input signal (either live or prerecorded voice or music) which has been converted into an electrical voltage signal (2) and split into four separate but substantially equivalent signals (7A-D) by a digital delay device (6). Each of said conduction loops is associated with a pair of connectors (14) which are in close proximity to each other, though electrically isolated from one another. This results in an end signal which is substantially independent of the location and the orientation of a hearing aid device. Said multiple conduction loop array (12) is bound into a flexible, lightweight mat (16) which can be unrolled in the area to be addressed.



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INDUCTION-BASED ASSISTIVE LISTENING SYSTEM**TECHNICAL FIELD**

5 This invention relates to the field of systems for addressing hard-of-hearing persons, especially in a classroom or auditorium setting where a single speaker is addressing an audience of many listeners. More particularly, this invention relates to systems whereby communication to hard-of-hearing persons is mediated by an audio-frequency magnetic field
10 generated by and correlated with the speech and other sounds to be communicated, said field being sensed by the small pick-up coil embedded in most hearing aid units. This invention furthermore constitutes a modular approach to an improved induction loop system, wherein the specific layout of a multiplicity of convoluted loops and the
15 phases selected for the currents through said loops produce an ac magnetic field which is highly homogeneous throughout the target area, has minimal spillover beyond the target area, and which leads to a hearing aid response that is substantially isotropic, i.e., independent of the position and orientation of the hearing aids.

20

BACKGROUND ART

 It is estimated that some 20,000,000 Americans have some form of hearing loss that affects their ability to understand the spoken word in certain listening situations. Approximately one in every five children has a
25 hearing loss in one or both ears that is at least medically significant and as many as seven children per thousand have a hearing loss that is educationally or socially significant. Similarly, as the United States population grows older there will be more and more people with significant hearing loss.

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Conduction-type hearing losses and certain nerve-type hearing

losses can be at least partially remedied by the use of standard hearing aids which electronically amplify sound waves received at the ear.

Traditionally, these systems have incorporated a sensor of sound waves, transducer means of converting the sound wave signal into an electric voltage, means of amplifying the electric voltage, and a second transducer for converting the amplified voltage back to sound waves which are then directed to the eardrum. Current hearing aids have the ability to increase sound intensity (amplitude) over the entire spectrum of normal speech frequencies; their circuitry may be also be tailored so as to amplify only a particular frequency range and thus compensate for the specific hearing loss of a particular individual.

Unfortunately, hearing aids amplify unwanted sounds as well as desired sounds. Since one of the major problems confronting those who are even slightly hearing-impaired is that of differentiating the desired sound (the signal) from the undesired background sounds (the noise), universal amplification of all ambient sounds is highly undesirable; it does not increase the signal-to-noise ratio. The hearing aid which provides assistance in a one-to-one conversation does not work nearly as effectively in the classroom, the theater, or on the job. Thus, without further advances, the traditional hearing aid does not effectively remove the barrier which exists between the hearing-impaired person and his or her education, employment and recreation. Since one of our societal goals is to provide all physically-handicapped persons with access to such facilities and activities which is equal to that of the population as a whole, there is great pressure to go further in the enhancement of signal-to-noise ratios for the hearing-impaired person listening to speech and other sounds in public places such as schools, museums, concert halls, etc. In a sense, these efforts can be characterized as being directed toward the creation of a "barrier-free environment" for the hearing-impaired.

As a practical matter, creating this barrier-free environment has to be done without burdening hearing-impaired persons with cumbersome equipment and without interfering with the listening efficiency and enjoyment of people with more acute hearing. The three general approaches are currently in use for addressing hearing-impaired individuals in a classroom or auditorium setting can be characterized as follows.

1. **Radio transmission** (commonly referred in the field as "frequency modulation" systems although some set-ups utilizing amplitude modulation are in use), wherein the audio-frequency signal to be conveyed is used to modulate a radio-frequency carrier wave being transmitted to special receivers located near each individual to be addressed. This modulated transmission is de-modulated by the receiver system and the resulting audio-frequency wave fed into the hearing aid or earphone of said individual.

2. **Light transmission** (also referred to as "infra-red systems" or "infra-red modulation"), wherein the audio-frequency signal to be conveyed is used to modulate infra-red beams which are then picked up by special receivers located near the individuals to be addressed. In principle, this is the same as Approach 1 above, just the frequency of the electromagnetic carrier is changed.

3. **Audio-frequency magnetic fields** (created by what are generally referred to as **Induction Loop Systems**), wherein audio-frequency magnetic fields correlated with the sounds to be conveyed are created directly at the location of the individual to be addressed. These magnetic fields then induce audio-frequency voltages in the pick-up coils already embedded in most hearing aids, audio-frequency voltages which after amplification enter a transducer which directs sound waves to the ear of the listener.

Each of these approaches as currently used has serious disadvantages. The first one, **radio transmission** from the speaker to the

audience -- effectively a closed-circuit radio broadcast within the room -- requires rather expensive transmitting equipment and requires that the hearing aid (by itself or enhanced with other electronic equipment) be capable of receiving radio signals, a requirement which leads to

5 cumbersome and obtrusive equipment near the listener. Furthermore, there exists the potential for "cross-talk" if the listener is in the vicinity of two radio transmission systems operating at the same carrier frequency. It is true that in fixed school building contexts, the radio transmission system is set up to operate on several different carrier frequencies and in this way

10 adjacent classrooms can utilize the system concurrently. This does require that the listener know what frequency to have his or her receiver tuned to. Although this may not be a burden when the listener continues to return to the same classrooms and listening systems, it does limit the use of radio transmission systems for general purpose applications where the listener

15 may not be able to prepare in advance to receive the frequency in use. On the other hand, attempts to standardize the transmitting frequency lead back to problems with cross-talk with consequent deterioration in signal resolution for the listener.

20 Although the infrared **light transmission** system -- relying on a directed (and easily contained) electromagnetic wave -- does not have the "spillover" problems inherent in the radio transmission method, it still requires transmission and receiving equipment which is obtrusive and calls attention to the listener. Moreover, and unlike the situation with the radio

25 transmission system, the listener has to ensure that his or her detector is out in the open and in the line of sight with the light source. Additionally, infrared tends not to work well in bright sunlight, presumably because the infrared component of the sunlight saturates the receiver/demodulator units.

30 Because it can utilize a detector already present in most hearing aids with no need of external receiver/demodulator electronics, the

induction loop system (ILS) technology has been more widely used throughout the world than either of the other two. Its convenience of implementation grew out of the realization that telephone receivers produce externally-detectable audio-frequency magnetic fields correlated to the speech patterns being received by the telephone. This realization led to the introduction into hearing aids of tiny pick-up coils and the related circuitry needed to detect and amplify the telephone-generated magnetic field signal and then to convert it back into a sound signal to be directed toward the eardrum. In order to activate the pick-up coil detector (and to deactivate the straight sound wave detection/amplification system in the hearing aid) the user simply flips a switch on the hearing aid unit. This is typically what will be done when the hearing aid user is conversing on the telephone. Of course, once the pick-up coil (the telephone coil or "T-coil") circuitry was in place it could be used for more general communication with the hearing-impaired, and in particular any communication mediated by an audio-frequency magnetic field established at the location of the hearing aid.

Generating the required audio-frequency magnetic field can be done most simply by placing a planar conducting wire loop around the area or room in which the target audience is located, a loop which is energized by an audio-frequency current generated electronically from, and correlated with, the speech and other sounds to be communicated. More particularly, that current is generated by a simple microphone/amplifier/speaker output circuit in which the conducting loop replaces the speaker. A horizontal planar loop results in a predominantly vertical ac magnetic field being generated inside the loop, which is where the audience would be intended to sit or stand. Unfortunately, disadvantages to the basic ILS exist which counter the simplicity of design and universality of application. For one thing, the spillover problem is significant; at a distance from the loop equal to half the loop's width the audio-frequency magnetic field strength

remains equal to half the maximum amplitude *within* the loop. When one combines this slow dropoff with the logarithmic response of the human ear, it can be seen that the single-loop ILS is unusable for addressing audiences in adjacent rooms within a building, a real limitation when setting up communication systems within the school building setting, especially for a school attended primarily by the hearing-impaired. Even in those exceptional circumstances where spillover might not need to be considered -- for example, buildings with a single large auditorium¹ -- one must still confront the high degree of directionality (anisotropy) in the signal received. This follows from the fact that at a given location within the loop the ac magnetic field generated oscillates back and forth in a specific fixed direction. In the center of the loop this direction is close to vertical (at locations not far above the plane of the loop). A maximum signal is induced in the T-coil of the hearing aid when the plane of the T-coil is perpendicular to said fixed direction of the ac magnetic field (which near the center of the loop would occur when the listener was holding his or her head upright). Conversely, the induced signal is zero when said plane is oriented so as to *include* said fixed direction. This means that whenever the listener nods or tilts his or her head the sound received by this technique varies in intensity, actually falling to zero for certain orientations. More specifically, these effects occur for the listener at the center of the loop when said listener rotates his or her head about any other axis than the vertical. At each location in the loop there will be one and only one axis of symmetry as far as reception of the signal is concerned. Near the edges of the loop, that axis will be approximately horizontal (and oriented perpendicular to the wire constituting that side of the loop). A further disadvantage of the simple ILS is fluctuation which occurs in the signal reception amplitude as the listener moves about within the loop, even

¹ Even in this instance, one might be concerned about spillover affecting 30hard-of-hearing persons near to the auditorium who have their hearing aids switched to the T-coil in order to use a telephone.

though the hearing aid orientation and height above the floor remain constant. This fluctuation occurs because of the change in both amplitude and direction of the audio-frequency magnetic field as one moves about within the loop. A final major impediment to the wider use of ILSs -- one
5 *not* present with the radio and infrared systems -- is the need to lay the loop out with care each time it is installed or moved from one room to another. A nuisance when one is dealing with a single loop, this need creates significant problems when one is working with the more complicated loop arrays to be discussed below.

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In an early attempt to deal with spillover, the single loop was folded so that it had a series of rectangular lobes. This greatly reduced spillover since 1) it permitted a lower current to be used (the convolution of the loop ensures that all regions are close to the current-carrying wire) and 2)
15 it resulted in partial cancellation of the audio-frequency magnetic field away from the target area. Unfortunately, it greatly increased the non-uniformity of the vertical component of the ac magnetic field *within* the target area. To address *that* problem, a second multi-lobe loop was introduced -- and energized by a current identical to that in the first loop except for its
20 phase, which was shifted by ninety degrees. This additional modification restored the uniformity of the magnetic field amplitude which had existed within the large single loop. See, for example, *A New Approach to a Space-Confined Magnetic Loop Induction System*, D. Bosman and L. J. M. Joosten, IEEE Transactions on Audio, Vol. AU-13 May/June 1965. Note
25 that when Bosman and Joosten use the term "multi-loop system," they are referring to a single loop with a number of lobes. What they describe in the referenced paper is a system with two such loops, oriented parallel to one another and powered by currents wave forms which are identical except for their respective phases, which differ by ninety degrees. (U.S.
30 Patent 4,361,733, Marutake et al., November, 1982, incorporates and describes the approach of Bosman and Joosten.) This early attempt to

salvage the ILS did not address the problems of anisotropy and complexity of installation. The "dead zones" which Bosman and Joosten sought to eliminate were those areas where the *vertical* component of the audio-frequency magnetic field fell to zero. They did not address the fact that if the system is limited to utilizing just the *vertical* component of the induction field then, throughout the target area, the listener can lose the signal completely for a wide range of pick-up coil orientations. In other words, the system of Bosman and Joosten still leaves "dead *angles*," angles of the hearing aid for which no signal is received.

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U.S. Patent 4,489,330, **Marutake et al.**, December, 1984, addresses the anisotropy problem, but approaches it from the direction of the hearing aid rather than that of the loop system. Recognizing that with all of the previously-available Induction Loop Systems there was a serious anisotropy problem, these inventors disclosed modified pick-up coil circuitry for the hearing aid itself. With a multiplicity of hearing aid pick-up coils, each oriented at a different angle and electrically coupled with one another, it is possible to largely overcome the anisotropy in the audio-frequency magnetic field set up by the ILS. That is, U.S. Patent 4,489,330 of **Marutake et al.** takes the ILSs as described in the prior art and re-designs the receiving device, the hearing aid, so as to partially overcome the deficits in existing ILSs. Unfortunately, this approach has the serious drawback of requiring the many listeners to modify *their* systems, instead of modifying the single system of the speaker so as to take full advantage of the hearing aid circuitry already in place.

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Further work with the two-loop system resulted in the second multi-lobe loop being physically oriented so that the horizontal components of the audio-frequency magnetic fields generated by the two loops were generally perpendicular to one another. (The ninety-degree phase difference between the currents in the respective loops was maintained. In

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addition, the multi-lobe deployment of each of the two loops is maintained so as to minimize spillover.) See *Improvement of Induction Loop Field Characteristics Using Multi-Loop Systems with Uncorrelated Currents*, by Ake Olofsson, Report TA110, Karolinska Institutet Dept. of Technical

5 Audiology (Jan 1984).² Some decrease in anisotropy results, since with the two currents physically and electrically orthogonal to one another the resultant audio-frequency produces two axes of symmetry about which the T-coil can be rotated without changing the signal received. This enables the listener in the center of one of the sub-loops to turn his head about a

10 vertical axis and also to nod his head about a single horizontal axis without suffering a great reduction in signal. Nevertheless, there remain dead angles at all locations in the target area. Furthermore, the installation of this orthogonal loop system is fairly demanding, something which in general cannot be done by the end user if optimum design results are to

15 be approached. Obviously, any system which requires a great deal of effort to set up will encounter resistance among those responsible for purchasing and installing it.

In summary, the really successful implementation of an Induction

20 Loop System awaits design which will produce a signal which is 1) localized (minimal spillover), 2) homogeneous (minimal signal variation as one moves around the target area) and 3) isotropic (minimal signal variation as one changes the orientation of the hearing aid). It must also incorporate a loop configuration which is easily installed and easily moved

25 from one room to another. The present invention makes important advances in all four of these areas when compared with the prior art.

² In spite of the title, this paper is limited to a discussion of systems with two loops, each of which is deployed with multiple lobes. At its conclusion it conjectures about possible benefits of using more than two loops, but provides no design suggestions or technical studies of such systems. Olofsson also alludes in passing to the use of a time-delay in place of the phase shift.

The current invention uses a new configuration of induction loops and phase shifts that produces a magnetic field capable of inducing in a pick-up coil a voltage that is substantially uniform in strength regardless of the orientation of the pick-up coil. The configuration also results in the generation of a magnetic field whose strength decreases rapidly outside of the boundaries of the induction loops, thus allowing the inventor's system to be set up in adjacent rooms without the complication of cross-talk. Finally, the present invention utilizes a flexible mat in which the loop configuration is embedded, thus permitting easy deployment of the communication system.

DISCLOSURE OF THE INVENTION

5 The underlying invention is two-fold. On the one hand the Induction
Loop System disclosed introduces a specific new multiple-loop
configuration which when energized by similar currents mutually time-
shifted by certain amounts generates an ac magnetic field which is highly
localized and so structured so as to give rise to a signal which is both
homogeneous and isotropic throughout a defined target area. On the
10 other hand, the multiple-loop system disclosed is incorporated into a mat
matrix which can be rolled up like a rug and transported as a unit to the
room where it is to be installed; thus the need for a tedious, time-
consuming deployment of the loop system is eliminated and a modular
approach to "looping" rooms of varying dimensions is introduced.

15

 The best results with respect to homogeneity are obtained by using
pairs of individually energized loops. Each individual loop is arranged to
have a series of sub-loops, rectangular in shape, with the long dimensions
of all the rectangular sub-loops parallel to one another. The other loop of
20 the pair is similar, and has its sub-loops oriented in the same way as the
first member of the pair, but displaced from the first set of sub-loops by
some fraction of the width of an individual sub-loop. In order to
significantly reduce the anisotropy of signal detection, at least two such
pairs are needed, the second pair being deployed so that all of *its* sub-
25 loops are physically rotated by ninety degrees with respect to those of the
initial pair. (Balancing cost versus sound quality, a single pair of loops can
be used in conjunction with an individual loop oriented so that its sub-
loops are positioned at right angles with respect to the sub-loops of the
pair. With a proper distribution of power and selection of time delays, this
30 minimal system can greatly reduce the anisotropy of signal detection;
nevertheless, the homogeneity of signal detection as well as its isotropy

suffer in comparison with the configuration which utilizes a second full pair.)

5 The best results with respect to isotropy of signal are obtained when the currents in the individual loops are shifted from one another by time intervals on the order of milliseconds. (Use of a delay of greater than about 16 to 20 milliseconds results in a chorusing effect in the detected signal whereas use of a delays much less than a few milliseconds results in anisotropic signal detection thus eliminating the advantages of the present invention.) Each individual loop is powered separately, so that, for
10 example, with two pairs, one will need four separate circuits for supplying current and three time shifters so as to ensure that the audio-frequency magnetic fields produced by the respective loops are separated from one another in the time domain.

15 The system comprises known transducer means for converting a sound-wave input signal into a corresponding electric voltage signal, known means for separating the electric voltage signal into a multiplicity of current signals, electrical delay means for delaying the current signals with respect to the reference signal by times on the order of milliseconds, and
20 known means for connecting said current signals to said separate loops. The conduction loops are all affixed to a mat or sandwiched between a pair of mats that can easily be laid on the floor of the room in which the the audience is to be addressed, or which can constitute one of a set of
25 such mats. Only the connections by which the individual loops are connected to the rest of the electronics extend outside of the mat.

30 The time delay approach used by the invention to separate the four audio-frequency magnetic fields appears to have an advantage over the use of phase shifting. Any sound waveform, no matter how complex, can be resolved into a collection of pure sinusoidal waves, each with a well-

defined frequency -- the so-called Fourier components of the complex waveform. With the time delay method utilized in the present apparatus, each of the individual Fourier components is delayed by the same time interval, which means that the entire waveform (the packet of the individual Fourier components) is delayed intact. In contrast, the use of the typical phase shifter device will delay each Fourier component by the same phase, with the result that there can be more distortion in the end signal.

BRIEF DESCRIPTION OF THE DRAWINGS

5 **Figure 1** is a block diagram of the preferred embodiment of the multi-loop induction hearing aid system.

Figure 2A shows the outline of the first of four individual conduction loops in the preferred embodiment.

Figure 2B shows the outline of the second of four individual conduction loops in the preferred embodiment.

10 **Figure 2C** shows the outline of the third of four individual conduction loops in the preferred embodiment.

Figure 2D shows the outline of the fourth of four individual conduction loops in the preferred embodiment.

15 **Figure 2E** shows the composite of the four individual loops as they are arrayed together within a mat in the preferred embodiment.

Figure 3 shows a detail of the mat construction, showing a corner of the mat in the preferred embodiment with portions of two individual loops included.

BEST MODE FOR CARRYING OUT THE INVENTION

A block diagram of the preferred embodiment of the multi-loop induction hearing aid system is shown in **Figure 1**. An input transducer 1 converts an input signal (either live or prerecorded voice or music) into an electrical voltage signal 2. Said electrical voltage signal is conditioned *seriatim* by an audio mixer 3, a graphic equalizer 4, and a signal limiter 5 before being fed into a digital delay device 6. Said digital delay device 6 first splits said electrical voltage signal 2 into four separate but substantially equivalent signals 7A-D. Said signals 7A-D are then subjected to delay circuitry 8 of said digital delay device 6. Said signal 7A is delayed by zero milliseconds, said signal 7B by four milliseconds, said signal 7C is by six milliseconds, and said signal 7D by eight milliseconds. Delayed signals 9A-D (even though said signal 7A is not subjected to delay, it is helpful to include it in this grouping) are amplified by a four-channel amplifier 10, the output of which comprises four delayed, amplified voltage signals 11A-D, which are connected to a set of leads protruding from a multiple conduction loop array 12 which defines a square approximately 3.5 meters on a side. The net result is that all of the individual electrical signals and Fourier components therein are time shifted relative to one another. This inherently results in corresponding Fourier components in different time shifted signals being phase shifted by different amounts (not considering the possible equivalency of phase angles when multiples of 2 pi radians are subtracted, as would be done if one were computing arguments for trigonometric functions).

Figure 2A shows a first individual conduction loop 13A, **Figure 2B** shows a second individual conduction loop 13B, **Figure 2C** shows a third individual conduction loop 13C, and **Figure 2D** shows a fourth individual conduction loop 13D. In the preferred embodiment, the conductor used for each of said individual conduction loops 13A-D is 20-gauge stranded wire

with nylon-clad PVC insulation. Said individual conduction loops **13A-D** are shown as they appear, respectively, before being incorporated into said multiple conduction loop array **12**. Associated with each of said conduction loops **13A-D** is a pair of connectors **14**. Electrical connections are made to said pairs of connectors **14** so that voltage signal **11A** is connected to individual conduction loop **13A**, voltage signal **11B** is connected to individual conduction loop **13B**, and so on. When said individual conduction loops **13A-D** are combined in said multiple conduction loop array **12**, said pairs of connectors **14** from the respective individual conduction loops **13A-D** are in close proximity, though electrically isolated from one another. Viewing **Figures 2A-D** with this proximity constraint in mind, it is possible to envision the relative orientations and relative displacements of said individual conduction loops **13A-D** with respect to one another.

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In the preferred embodiment, each of said individual conduction loops **13A-D** comprises a pair of rectangular sub-loops **15** connected by a narrow section where the wires making up the loop run side-by-side. Each of said sub-loops **15** is further defined as having its length dimension equal to about four times its width dimension, which in the preferred embodiment means that said sub-loops **15** each define rectangles approximately 3.5 meters long and one meter wide.

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Said individual conduction loops **13A-D** are associated pairwise, a first pair comprising said first individual conduction loop **13A** and said second individual conduction loop **13B** and a second pair comprising said third individual conduction loop **13C** and said fourth individual conduction loop **13D**. Said first pair of individual conduction loops **13A** and **13B** is arranged such that the respective sub-loops **15** of said first conduction loop **13A** are oriented parallel to said sub-loops **15** of said second conduction loop **13B**, and are physically displaced by a distance equal to

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the width dimension of a single sub-loop 15. Said second pair of individual conduction loops 13C and 13D is arrayed similarly but rotated physically by ninety degrees with respect to said first pair of individual conduction loops 13A and 13B.

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Figure 2E illustrates said multiple conduction loop configuration 12 defined collectively by said individual conduction loops 13A-D. Said multiple conduction loop configuration 12 is bound into a flexible mat 16. In the preferred embodiment, said flexible mat 16 is comprised of a top layer 17 and a bottom layer 18 of elastomer-coated nylon mesh carpet pad material, wherein said top layer 17 is combined with said bottom layer 18 in such a way as to envelop said multiple conduction loop array 12 in a sandwich-like configuration. Figure 3 illustrates a detail of said flexible mat 16 in combination with said multiple conduction loop array 12. Said multiple conduction loop array 12 is fastened to said flexible mat 16 using any appropriate fastening means known in the art. In the preferred embodiment, said fastening means are "hog ring" fasteners 19. Said multiple conduction loop array 12, because its described permanent mounting on said flexible mat 16, is mobile and can be rolled out on the floor before the arrival of an audience and removed and stored at other times.

The location of the target audience's listening devices is directly above said flexible mat 16, at heights ranging from zero to approximately one meter. With the present invention, the magnetic field amplitude at a fixed height above said flexible mat 16 is essentially constant, not varying by more than ± 0.5 dB. This constancy also pertains to varying the orientation of the listening device about any axis and by any amount. In contrast, the amplitude of the audio-frequency magnetic field declines sharply away from the target space, both for lateral and vertical displacements. At a height of one meter above said flexible mat 16 in the

preferred embodiment and at a lateral displacement of 0.6 meter from the outer edge of said flexible mat 16 said amplitude is 20 dB lower than it is in the area directly above said flexible mat 16. Additionally, there is a rapid fall-off as one moves upward or downward with respect to the target space, the region directly above said flexible mat 16. In particular, at an elevation of 2.75 meters above said flexible mat 16, said amplitude is down by 43 dB from its level directly on said flexible mat 16 (zero elevation); furthermore said amplitude at 2.75 meters above said flexible mat 16 is down by 23 dB from its level at one meter elevation, the upper height of the normal target region. Consequently, the Induction-Based Assistive Listening System as described in this preferred embodiment can be installed and used in rooms which are adjacent to one another, either displaced laterally on the same floor or one above the other. Furthermore, the modular aspect of said flexible mat 16 containing said multiple conduction loop array 12 simplifies the enlargement of the communication system to encompass a large auditorium space.

Although the present invention has been described primarily with reference to the preferred embodiment, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What I Claim is:

1. A system for addressing hearing-impaired persons within a targeted audience by the generation of specifically configured audio-frequency magnetic fields at pick-up coils worn by said hearing-impaired persons comprising:
 - a) transducer means for converting an acoustic signal into an electrical voltage signal possessing substantially the same Fourier spectrum as said acoustic signal;
 - 10 b) means for dividing said electrical voltage signal into a multiplicity of identical electric voltage signals;
 - c) time delay means for introducing various discrete delay times into each of said multiplicity of identical electric voltage signals so as to produce a multiplicity of delayed electrical voltage signals;
 - 15 d) means to amplify each of said delayed electrical voltage signals;
 - e) a grid of electrical conductors embedded in a flexible mat wherein said mat comprises:
 - 20 i) a bottom layer of flexible material;
 - ii) a top layer of flexible material;
 - iii) means for fastening said top layer over said bottom layer so as to sandwich said grid between said top layer and said bottom layer;
- 25 and said grid comprises a planar arrangement of at least one pair of electrically isolated conduction loops, each of said conduction loops further comprising an electrically-linked plurality of substantially uniform, substantially rectangular sub-loops, each rectangular sub-loop having a length dimension equal to approximately four times its width dimension and
- 30 further where all of said sub-loops of one member of a given

5 pair of said conduction loops are arrayed so as to have their long sides parallel to the long sides of all of said sub-loops of the other member of said pair and are further arranged so that each of said sub-loops of one member of said pair is displaced along its width dimension by a distance equal to one-half the magnitude of said width dimension from the nearest sub-loop belonging to the other member of said pair of electrical conductors; and

10 f) means for connecting each of said time-delayed electrical voltage signals to a single one of said conduction loops so as to generate a single current in said single one of said conduction loops such that the current variation produces the same waveform which was associated with said acoustic waveform and where current amplitude produces an audio-
15 frequency magnetic field amplitude of approximately 100 ma/meter at an elevation of 0.5 meters above said mat.

2. A system for addressing a selected audience of hard-of-hearing persons by the generation of specifically configured magnetic fields in the
20 vicinity of pick-up coils worn by said audience comprising:

- a) transducer means for converting an input signal into an electrical voltage signal possessing substantially the same Fourier spectrum as said input signal;
- 25 b) means for separating said electrical voltage signal into a multiplicity of current signals, phase shifted with respect to one another, in which each Fourier component of a particular member of said multiplicity of current signals has a unique phase shift with respect to the corresponding Fourier component in each of the other members of said multiplicity
30 of current signals;
- c) an essentially planar arrangement of substantially rectangular,

5 electrically isolated conduction loops, each of said conduction loops having a length dimension and a width dimension, said conduction loops further arranged such that there exists a first loop which has an orientation with respect to said first loop's length dimension and at least one additional conduction loop which has an orientation with respect to said additional loop's length dimension which is essentially perpendicular to said orientation of said first loop and a further conduction loop which has an orientation with respect to said further loop's length dimension which is essentially parallel to said orientation of said first loop such that magnetic fields induced by current flowing through said conduction loops are of substantially uniform strength in a plane parallel to said mat when measured in an area above said conduction loops, but said magnetic fields are of substantially reduced strength outside of the area of said conduction loops; and

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20 d) means for connecting each of said phase-shifted current signals to a separate conduction loop of said arrangement of conduction loops, wherein a voltage signal corresponding to said input signal is induced in said pick-up coils of said audience.

25 3. The system of **Claim 2** in which each of said conduction loops is configured in the form of a plurality of substantially rectangular sub-loops, each sub-loop having a length dimension greater than a width dimension.

30 4. The system of **Claim 3** in which all of said sub-loops have the same dimensions.

5. The system of **Claim 4** in which said length of said sub-loops is

about four times that of said width of said sub-loops.

5 6. The system of **Claim 4** in which said sub-loops of essentially parallel conduction loops are arranged in pairs such that the sub-loops of a first conduction loop physically correspond with a second conduction loop displaced longitudinally by one sub-loop.

10 7. The system of **Claim 2** in which said conduction loops are arranged in pairs.

8. The system of **Claim 2** in which said transducer means comprises a microphone.

15 9. The system of **Claim 2** in which said arrangement of conduction loops are contained in a flexible mat.

10. The system of **Claim 9** in which said flexible mat is of lightweight construction.

20 11. The system of **Claim 2** in which said means for separating said electric voltage signal comprises an electronic digital delay.

25 12. A modular system for addressing a selected audience of hard-of-hearing persons by the generation of specifically configured magnetic fields in the vicinity of pick-up coils worn by said audience comprising:

- a) transducer means for converting an input signal into an electrical voltage signal possessing substantially the same Fourier spectrum as said input signal;
 - b) means for separating said electrical voltage signal into a multiplicity of current signals, phase shifted with respect to one another, in which each Fourier component of a particular
- 30

member of said multiplicity of current signals has a unique phase shift with respect to the corresponding Fourier component in each of the other members of said multiplicity of current signals;

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c) a plurality of flexible mats comprising:

i) a bottom layer of flexible material;

ii) an essentially planar arrangement of at least three substantially rectangular, electrically isolated conduction loops, each of said conduction loops having a length dimension and a width dimension, said conduction loops further arranged such that there exists a first loop which has an orientation with respect to said first loop's length dimension and at least one additional conduction loop which has an orientation with respect to said additional loop's length dimension which is essentially perpendicular to said orientation of said first loop and a further conduction loop which has an orientation with respect to said further loop's length dimension which is essentially parallel to said orientation of said first loop such that magnetic fields induced by current flowing through said conduction loops are of substantially uniform strength in a plane parallel to said mat when measured in an area above said mat, but said magnetic fields are of substantially reduced strength outside of the area of said mat; and

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iii) a top layer of flexible material; and

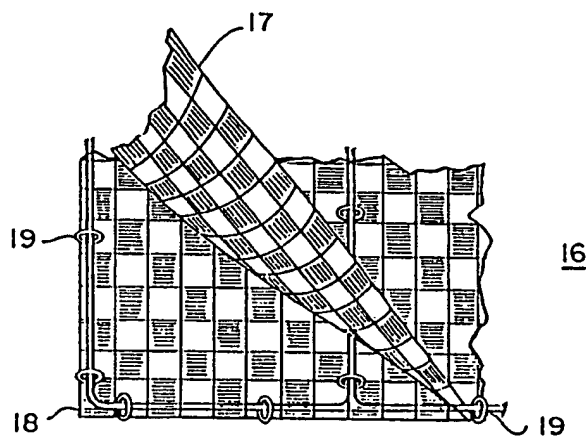
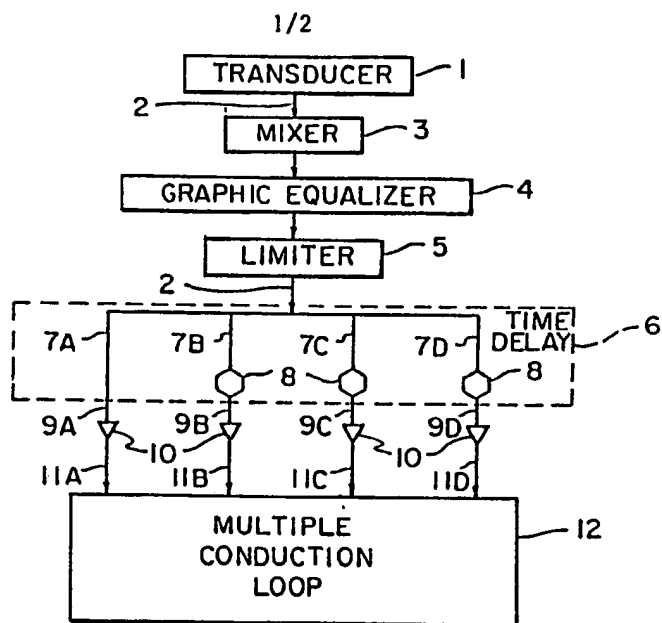
d) means for connecting each of said phase-shifted current signals to a separate conduction loop of said arrangement of conduction loops, wherein a voltage signal corresponding to said input signal is induced in said pick-up coils of said audience.

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13. A method of addressing a selected audience of hard-of-hearing persons by the generation of specially configured magnetic fields in the vicinity of pick-up coils worn by members of said audience comprising:

- 5 a) converting an input signal into an electrical voltage signal possessing substantially the same Fourier spectrum as said input signal;
- b) separating said electrical voltage signal into a multiplicity of current signals, phase shifted with respect to one another, in
10 which each Fourier component of a particular member of said multiplicity of current signals has a unique phase shift with respect to the corresponding Fourier component in each of the other members of said multiplicity of current signals;
- c) conducting each of said current signals into a corresponding
15 electrically isolated conduction loop, each conduction loop having a substantially rectangular configuration and a length dimension and a width dimension, wherein a voltage signal corresponding to said input signal is induced in said pick-up
20 coil of a member of said audience, said conduction loops situated in an essentially planar configuration such that there exists a first conduction loop which has an orientation with respect to said first loop's length dimension and at least one additional conduction loop which has an orientation with
25 respect to said additional loop's length dimension which is essentially perpendicular to said orientation of said first loop and at least one further conduction loop which has an orientation with respect to said further loop's length dimension which is essentially parallel to said orientation of said first loop
30 such that magnetic fields induced by current flowing through said conduction loops are of substantially uniform strength in a plane parallel to said mat when measured in an area above

said conduction loops, but said magnetic fields are of substantially reduced strength outside of the area of said conduction loops.



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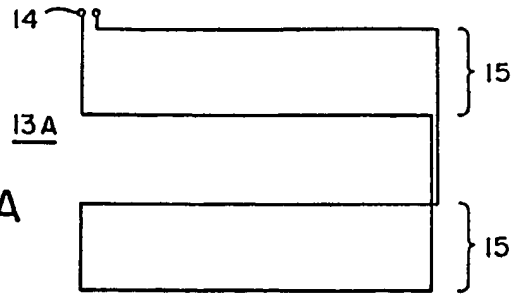


FIG. 2A

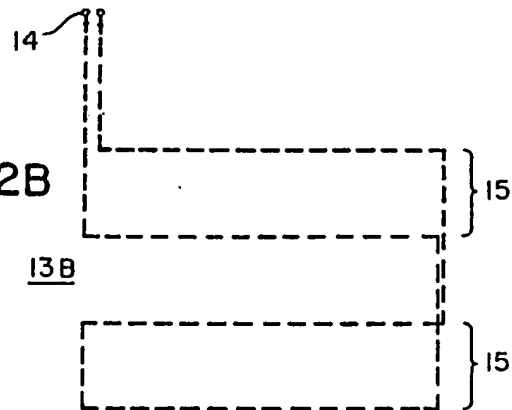


FIG. 2B

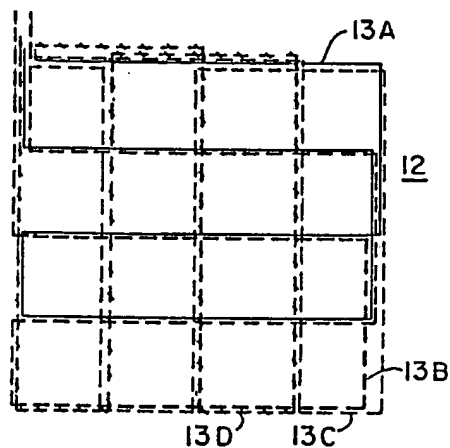


FIG. 2E

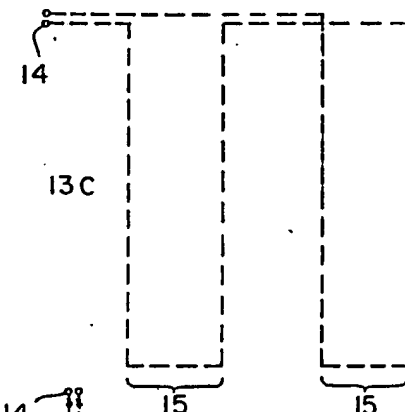


FIG. 2C

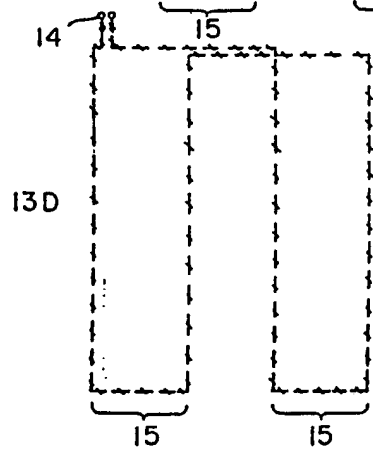


FIG. 2D

INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/01281

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ³ According to International Patent Classification (IPC) or to both National Classification and IPC INT. CL.(5): H04B 5/00 U.S. CL.: 381/79		
II. FIELDS SEARCHED <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black; margin: 5px 0;">Minimum Documentation Searched ⁴</div> <div style="display: flex; justify-content: space-between;"> Classification System : Classification Symbols </div> <div style="margin-top: 10px;"> U.S. 381/79; 455/41; 379/55 </div> <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black; margin-top: 10px;">Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁵</div>		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴		
Category ⁶	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁵
A	US, A, 2,252,641 (POLIAKOFF ET AL.) 12 August 1941.	
A	US, A, 2,461,344 (OLSON) 08 February 1949.	
A	US, A, 2,976,419 (MENKE ET AL.) 21 March 1961.	
A	US, A, 3,495,213 (NAHAS) 10 February 1970.	
A	US, A, 3,996,518 (HALSTEAD ET AL) 07 December 1976.	
A	US, A, 4,361,733 (MARUTAKE ET AL.) 30 November 1982.	
A	US, A, 4,489,330 (MARUTAKE ET AL.) 18 December 1984.	
A	"Yarmouth Man Markets Loop For Better Hearing" by MARIAN GAGNON, MAINESAY, Wednesday, 25 January 1989, page 19.	
A	"Improvement of Induction Loop Field Characteristics Using Multi-Loop Systems With Uncorrelated Currents", by AKE OLOFSSON, Karolinska Institutet, Dept. of Technical Audiology, Stockholm, Sweden, January, 1984.	
A	"A New Approach To A Space-confined Magnetic Loop Induction System", by BOSMAN and JOOSTEN, IEEE Transactions on Audio, Volume AU-13, No.3, May/June, 1965.	
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>¹⁸ Special categories of cited documents: ¹⁹</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search ² <div style="text-align: center; margin-top: 10px;">24 AUGUST 1990</div>		Date of Mailing of this International Search Report ² <div style="text-align: center; margin-top: 10px; font-size: 1.2em;">28 SEP 1990</div>
International Searching Authority ¹ <div style="text-align: center; margin-top: 10px;">ISA/US</div>		Signature of Authorized Officer ²⁰ <i>Ngoc Ho Nguyen</i> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> F.W. ISEN NGUYEN NGOC-HO </div> <div style="text-align: right; margin-top: 5px;">INTERNATIONAL DIVISION</div>

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

A

"Analytical Design of Magnetic Loop Induction Systems", by E. DE BOER, IEEE Transactions on Audio, Volume AU-13, No. 3, May/June, 1965.

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE¹

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers _____, because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim numbers _____, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out², specifically:

3. ☐ Claim numbers _____, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING²

This International Searching Authority found multiple inventions in this international application.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report covers the invention first mentioned in the claims; it is covered by claim numbers:
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority does not invite payment of any additional fee.

Remark on Protest

- ☐ The additional search fees were accompanied by applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.